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# **A SYSTEM FOR THE DIGITAL IMAGE ANALYSIS OF SPRAY SAMPLES**

*by*

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*Institute for Aerospace Research*

OTTAWA  
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# **A SYSTEM FOR THE DIGITAL IMAGE ANALYSIS OF SPRAY SAMPLES**

## **UN SYSTÈME D'ANALYSE D'IMAGE POUR L'ANALYSE D'ÉCHANTILLONS D'ARROSAGE**

by

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### **ABSTRACT**

A system for analyzing spray samples based on an electronic digitizing camera is described. The implementation and development of both the hardware and the software are discussed as well as the system performance. The system is capable of digitizing a sample into 1504 by 3008 pixels using 256 gray levels. The resolution is 10  $\mu\text{m}$  at the image plane and droplet diameters can be estimated with a most likely error of 3.5  $\mu\text{m}$ .

### **RÉSUMÉ**

Ce rapport décrit un système d'analyse d'échantillons d'arrosage basé sur une caméra digitale. On y résume le développement et la mise en oeuvre de l'équipement et du logiciel. Finalement, les performances du système sont présentées. Le système décompose chaque image d'un échantillon en 1504 par 3008 pixels en utilisant 256 niveaux de gris. La résolution dans le plan de l'image est de 10  $\mu\text{m}$  et les diamètres des gouttes échantillonnées peut être estimé avec une erreur statistique moyenne de 3.5  $\mu\text{m}$ .

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## 1) INTRODUCTION

In the course of our experiments on pesticide spraying, Kromekote<sup>TM</sup> cards were used to collect spray samples at ground level. The spray liquid has a red dye in solution and the resulting samples represent images with two colour states of red stains on a glossy white background (binary images). The analysis of these samples involves the measurement of the area and circumference of the stains from which data on the drop size and deposit density can be derived.

Pesticide sprays are made of droplets of diameters ranging from less than 10 to about 500  $\mu\text{m}$ . Droplets of a diameter less than 30  $\mu\text{m}$  have a settling velocity an order of magnitude smaller than the usual vertical turbulent velocity in the atmospheric surface layer. Thus their deposition efficiencies on any static collecting surfaces such as Kromekote cards are low. Because of the absorption of the liquid droplet into the sample card, the diameter of the stain visible on the card is about 3 times larger than the diameter of the droplet for a small droplet and 5 times larger for a 500  $\mu\text{m}$  droplet. The small droplets make relatively smaller visible stains than large droplets because the absorption process is not a linear function of droplet diameter. Therefore, to analyze a typical spray deposit one must measure stains of diameters ranging roughly from 100 to 2500  $\mu\text{m}$ .

Digitizing cameras decompose images into a series of discrete picture elements called pixels. At a pixel dimension of 20 by 20  $\mu\text{m}$ , stains 100  $\mu\text{m}$  in diameter are measured with an error of 20% and a 2500  $\mu\text{m}$  stain would be contained within a square area in the image plane measuring 125 by 125 pixels. Clearly, in order to obtain both the accuracy required to measure small stains and a significant number of large stains in a single field of view, we need to digitize our samples into a large number of pixels.

In the past, various image analysis systems have been used for spray deposit measurements. Typically, the image is collected by a commercially available video camera using either charge-coupled devices (CCD) (Bertollini et al., 1985) or tube technology (Sistler et al., 1982; Last et al., 1987). The image obtained with these systems is digitized into 512 by 512 picture elements or less and at a maximum of 8 bits of resolution per pixel. The number of pixels per line and the number of bits per pixel may have small differences from system to system but magnitudes of these parameters are roughly invariant. Therefore, none of those systems would fulfil our requirements. This has motivated our effort to develop an image analysis system which is capable of digitizing an image into 1504 by 3008 pixels at 8 bits of resolution per pixel (256 gray levels).

In this paper, both the hardware and the software that make up the system are described and the performance of the system

will be discussed.

## 2) SYSTEM HARDWARE

The system described in this report can be divided in four parts: the digitizing camera, the lighting system, the microcomputer and the interface between the computer and the camera.

A Datacopy<sup>TM</sup> Electronic Digitizing Camera<sup>2</sup> model 620 is used. The sensing element in the camera is a linear CCD array which is mechanically moved across the image plane. The CCD array which defines the Y-axis has 3456 elements, each element having an equivalent dimension of  $10.7 \times 10.7 \mu\text{m}$ . The spectral sensitivity of the detector covers wavelengths ranging from 0.4 to  $1.1 \mu\text{m}$ . The X-axis extends 4472 pixels and is in the direction of the CCD array motion. As this motion is continuous, each scan line (a line is in the Y direction) is distorted. The scan line skew is limited to 0.5 pixel and is consistent from line to line. Each pixel is assigned a gray level from 0 to 255 by the camera which defines the Z-axis. The Z-axis linearity is within 2 gray levels and the noise is limited to 0.25 gray level. The camera has an internal parallel

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<sup>2</sup>Mention of specific trade names does not imply endorsement of those products by Agriculture Canada or the National Research Council of Canada. Similarly, omission of product names is not intended as discrimination against those not mentioned.

interface with an 8-bit bi-directional data and command/status bus. The camera recognizes a variety of commands which control the scanning mode, the scanning window, the positioning of the CCD array and its velocity. The data are clocked out of the camera at a rate of 500 kHz and at maximum speed, a full frame of 4472 by 3456 pixels can be scanned in 35.5 sec.

The camera lens was designed and built at the Physics Division of the National Research Council of Canada. The design and fabrication of the lens are described in detail in Powell (1987 a). The lens specifications were based on our requirements for resolution at the object plane of 20  $\mu\text{m}$ , on the CCD array characteristics and on the camera design. A lens that could resolve 100 line pairs/mm over a circular area in the image plane of a diameter of 37 mm (1.46 in.) at a magnification of 0.5 was required. The back working distance had to be larger than 79 mm (3.11 in.) and the focal length as large as possible to maximize the uniformity of illumination across the image plane. A lens of focal length 100 mm was chosen. The field of view of the lens is  $\pm 6$  degrees at the corners giving a natural fall-off in illumination of 2% by the  $\cos^4$  law. The actual fall-off is somewhat higher at about 10%. This is probably due to the coating applied to the glass surfaces (Powell, 1987 b). The lens has a fixed effective numerical aperture of f/6 in the image space. Measurements have shown that the resulting lens can easily resolve 100 line pairs/mm. The lens design limits the useable scanning area to a circular surface of 3456 pixels

in diameter. In the implementation discussed here, the scanning area is limited to a rectangular window of dimensions  $X=1504$  pixels and  $Y=3008$  pixels located at the center of the image plane. Optical filters can be fitted in front of the lens to improve the contrast. A set of two green filters (Tiffen green1 series IV and Ednalite med. green) were used to enhance the red and white images.

The lighting system is based on four 75 watt, 12 volt halogen floodlights. These give much better results than standard incandescent lamps because they provide more energy in the blue-green range of the visible spectrum. The lamps are operated at a nominal voltage of 12.5 volts to increase further the blue-green content. One pair of lamps is placed on each side of the camera. Pieces of frosted glass are installed in front of the lamps to diffuse the light. The lamps are positioned to provide roughly even illumination of the target and at a sufficient distance away from the target to avoid saturation of the sensor array in the digitizing camera. The DC voltage applied to the lamps was controlled to within 0.01 volts to achieve repetitive measurements as discussed later in the text.

The camera, the lens and the lights are all rigidly mounted on a stand. Spatial rigidity is essential if repetitive measurements are to be performed. The lens cannot be moved independently of the camera and the focusing is done by changing

the camera-to-target distance using a micropositioner. The whole mechanism is locked in place once the focus is obtained. The sample holder is a small suction table which is required to make the target area flat. The camera and the lighting system are enclosed in a dark chamber to reduce errors introduced by fluctuations in the background illumination of the room.

The data are collected with a PC/AT microcomputer using a specially designed parallel interface. The interface was designed and built at the Flight Research Laboratory of the National Research Council of Canada. A custom built interface is necessary for the computer to cope with the 500 kHz data output rate of the camera. The interface serves two purposes. First, it is used as an output port to send commands to the camera. Second, it receives the data and stores them in an 352 kBytes on-board buffer in a first-in-first-out fashion. The data can then be read from the buffer by the computer for analysis. The buffer size limits the scanning to 101 full lines per buffer. Once the buffer is full, the data are analyzed, the buffer is cleared in preparation for the next batch of lines. The camera permits this start-stop operation without loss in accuracy.

### 3) SOFTWARE

The software required to obtain the area and the perimeter of the stains is described in this section. Beyond this point, the analysis of the data depends on the application.

#### 3.1) FOCUSING

To obtain a good focus, a single black to white transition perpendicular to the Y-axis is examined. The camera is set to read continuously a single line of data (X fixed). The sequence of events is as follows. After the data from the line are obtained from the camera, the slope  $dZ/dY$  is computed for all points along the line. The derivative is obtained using the following central scheme differentiator:

$$\left[ \frac{dZ}{dY} \right]_{Y_0} = \frac{1}{60} [Z_3 - 9Z_2 + 45Z_1 - 45Z_{-1} + 9Z_{-2} - Z_{-3}] \quad (1)$$

By adjusting the micropositioner, the camera is focussed by maximizing the slope at the transition. Once this is achieved, the camera is locked in place.

#### 3.2) BACKGROUND REMOVAL

At this stage the system is physically configured with a

well controlled light level. Figure 1 shows raw gray level data from a single line. The plot displays a smooth variation across the entire line, denoted the background, with some noise superimposed on it. The background results from variations in the light level across the object plane as well as from the vignetting effect and small imperfections of the lens. To remove the background, a white sampling card is scanned and the area is divided into square grid elements 47 pixels on a side. For each grid element, the average gray level is computed and stored in a background file. Then, as a sample is scanned, that background is subtracted from each pixel in the grid element. Figure 2 shows a plot of the gray level for a single line once the background is removed and a 200 gray level offset is introduced. This type of correction for the background has limitations because the drop-off in gray level where a line crosses a stain is not a purely additive phenomenon. Correcting by simply subtracting a background level is therefore a first order correction and should be used only when the maximum variation in the background is less than about 10%. The variation in the background could be kept within this limit by appropriate placement of the lamps as shown on the contour plot of gray levels (figure 3). There, the maximum range is only 15 gray levels when the spatial mean is at about the 205 level.

A systematic variation in the sensitivity from diode element to diode element along the array is another possible source of error which is classified as background. Although a

faulty diode cannot affect the background reading in a grid element by more than 2.1%, it could well lead to the detection of false stains. To measure the variation in sensitivity from diode to diode, 1504 lines were scanned. Then, for each of the diode elements, the average gray level reading was computed after removal of the background (figure 4). Diode to diode variability was found to be small. The standard deviation of the fluctuations in the mean had a value of 0.7 gray level which is small compared to an overall noise level of 1.9 gray levels. Therefore, the diode to diode variation can be ignored.

### 3.3) THRESHOLDING

The threshold is a gray level which is used to discriminate between useful signal and background. A gray level lower than the threshold corresponds to the signal. Once the background is removed, a single threshold value can be applied to the entire field of view.

A gray level distribution for a heavily stained card is bimodal (figure 5) with a separation between peaks of about 90 gray levels. The lower peak corresponds to the stained area and the higher one to the background while the valley between the two peaks never reaches zero gray level. This reflects the fact that the stain boundaries are seen as a gray level gradient rather than as a sharp edge. The mechanics of the droplet

spreading onto the surface of the Kromekote card, the diffraction pattern around objects in the plane of focus and the convolution of the discrete sensing array with the continuous image all contribute to this phenomenon. The optimum threshold level corresponds to the mid-point between the two peaks (Ahlers et al., 1985) which is 45 gray levels below the mean corrected background level. Figure 6 is a gray level plot for a single line showing the relationship between threshold level, background noise and the signal from the stains which appear as valleys. A threshold level of -45 clearly separates the signal from the noise.

The observation of "clean" cards under a microscope has revealed the presence of small dirt particles which are not easily removed from the surface. When a single threshold is applied, dirt particles cannot be discriminated from stains. To obtain an estimate of the importance of dirt particles, 75 non-stained cards have been scanned. With the exception of the largest observed stain with an area of 12 pixels, each of the stains had an area smaller than 10 pixels. Typically, the dirt particles that cannot be detected visually are either very small in size or have an elongated shape. Based on these observations, most dirt particles can be rejected using the following procedure. First, a clean portion of the sampling card, as evaluated visually, is exposed to the scanner and objects with an area smaller than 10 pixels are ignored. Finally, a circular shape factor (CSF) can be used to detect

elongated shapes. The CSF is defined as:

$$CSF = \frac{P_s^2}{4\pi A_s} \quad (2)$$

where  $A_s$  and  $P_s$  are the stain area and perimeter respectively. Theoretically, the CSF is equal to 1 for a perfectly circular area and larger than 1 for any other shape. Panneton (1989) has found that single stains can have a CSF as large as 1.25 when the area and perimeter are evaluated with the digitizing system. This is due to the path used to evaluate the perimeter. Elongated shapes have a relatively large CSF and are easily discriminated from nearly round stains. In applications where droplets from a narrow diameter spectrum are analyzed, the dirt particle problem can often be ignored, as in Panneton (1989).

The CSF can also be used to discriminate between round and overlapping stains such as object 3 on figure 7. When the CSF is larger than 1.25, the corresponding stain is treated as a set of overlapping stains. Panneton (1989) and Last (1987) presented approximate methods that can be used to account for overlapping stains.

### 3.4) SEGMENTING

Once a threshold has been chosen for the original image, a binary image results. Because of the camera design, analysis of the binary image is performed one X line at a time. It follows that regions of connected pixels on a given line are naturally grouped into line segments. Image segmentation refers to the operation where segments are linked to form objects. For example, segments 1 to 6 on figure 7 should be linked together to form object 1. This operation is straightforward for cases like objects 1 and 2 on figure 7 but requires more careful bookkeeping for objects similar to object 3. When the line containing segments 15 and 21 is reached these two segments appear to be the first segments of two distinct objects. The link between these two segments will be established only two lines below when segment 17 is analyzed. Therefore one needs to adopt a data structure which takes into account the possibility that segments that appear to have no connection when they are analyzed will have to be linked later on. This is achieved by introducing an intermediate object element between segments and objects which are called the lobes. A new lobe is created each time a segment that cannot be linked to another one on the previous line is reached. Thus, a lobe is created for every upward pointing projection in the image. Lobes are further classified into root or ordinary lobes. A root lobe is the first lobe of an object that is detected resulting in the identification of one root lobe per object. Ordinary lobes are

associated to root lobes using pointers allowing connected lobes to be grouped to form objects. The data structure is illustrated on figure 7.

When the data on the current line are processed, only the information describing the preceding line scanned is required. The information for these lines is stored as two sets of Y-coordinates for the start and end pixels of each line segment together with a vector of pointers for each line. Each vector has as many pointers as the number of segments on the line and each pointer points to the lobe to which the segment belongs. For computational efficiency, the end point of a line segment is defined as the first white pixel following the segment.

The logic flow for the segmenting process is illustrated in figure 8. On the figure,  $(YS_i, YE_i)$  refers to the start and end coordinate of the  $i^{th}$  segment on the current line while  $(YS_k, YE_k)$  are the start and end points of the  $k^{th}$  segment on the previous line. The parameter  $imax$  is the number of segments on the current line and the variable is a lobe counter. The logic flow in figure 8 works provided that a dummy segment is added to the previous line with start and end coordinates located outside the scanning window.

When a sample is scanned the  $(YS_i, YE_i)$  for the first line are loaded. Both  $i$  and  $k$  are initialized and each segment is treated as a new lobe, the lobe counter is incremented and the

data are stored. The data are the lobe area, the perimeter, the length of the longest segment per lobe and the edge flag. The path followed for the computation of the perimeter is illustrated on figure 7. The edge flag when set, identifies lobes that are touching one of the boundaries of the scanning area. The index  $i$  is incremented and the process repeated until  $i$  exceeds  $i_{max}$ . At this point, the program checks if the last line of the scanning window has been reached to decide whether it should stop or a new set of  $(YS_i, YE_i)$  has to be loaded. Prior to loading new data, the set of  $(YS_i, YE_i)$  is transferred to the  $(YS_k, YE_k)$  set.

After the first line has been analyzed, the logic flow passes through loop 1. Before entering the loop the edge flag is set for segments that are touching the frame boundaries. Loop 1 is designed to locate the first segment on the previous line to which the current segment could be linked. This is determined by the condition  $(YS_i > YE_k)$ . If this condition is true then the  $i^{th}$  and the  $k^{th}$  segments do not belong to the same lobe and loop 1 is executed once. The first operation in loop 1 verifies if the  $(i-1)$  segment has been linked to the current  $k$  segment with the test  $((YE_{i-1} < YS_k) \text{ or } i=1)$ . If this test is true none of the segments on the current line are linked to segment  $k$  which is then the last segment of a lobe. In that case, the lobe perimeter has to be updated. The variable  $k$  is then incremented by 1 and loop 1 is completed.

Leaving loop 1, the test ( $YE_i < YS_k$ ) is executed. If the condition is true, segment  $i$  cannot be linked to an existing lobe and a new lobe has been detected. The lobe counter is incremented, the data are stored and the next segment on the current line is considered. If the condition is false, segment  $i$  has to be linked to the root lobe to which segment  $k$  belongs. It is also necessary to verify if segment  $i$  constitutes a link between two or more lobes. This is the role of loop 2. This loop is entered if the condition ( $YS_{k+1} \leq YE_i$ ) is true which means that the lobe to which segment  $k+1$  belongs has to be linked to the lobe to which segment  $k$  belongs. Linking of the lobe is achieved using pointer variables. When a link is established, the perimeter needs to be updated. The variable is incremented and the loop repeated until no further linking is possible. Finally, the data of segment  $i$  are stored using its pointer to its lobe and a new segment on the current line can be analyzed. The whole process is repeated until the whole image is analyzed. When the segmentation process is complete, the following parameters have been computed for every lobe: an area, a perimeter, the length of the longest segment, an edge parameter and a pointer to a root lobe which is used to construct objects.

#### **4) SYSTEM PERFORMANCE**

In this section some parameters are presented that are

useful in assessing the performance of the system as well as in understanding its limitations.

#### 4.1) NOISE CHARACTERISTICS

The noise characteristics referred to here are related to the detailed variation of the gray level from any diode (pixel) relative to the background. In Section 3.2, it was described how the background was determined by scanning a white sample card and averaging the gray level over a grid of 47 by 47 pixels. This average was subtracted from the gray level at every pixel within this grid. It is expected that there would be variations around the mean from pixel to pixel. These variations can be referred to as noise because there is no stain data on the sample card used to determine the background. Dirt particles (see Sect. 3.3) as well as system variations can contribute to the variations.

In an attempt to remove the contributions of dirt particles to variations in gray level around the background, it was assumed that it was extremely improbable that three sample cards taken at random would have dirt particles at the same pixel. Further, any gray level lower than 10 below the background was taken to be caused by a dirt particle. This result occurred in about 4000 pixels out of the 4.5 million (3008 by 1504 pixel scanning window) pixels per card.

Scanning three cards and rejecting pixels with gray levels more than 10 below the background lead to a distribution of roughly 13.5 million gray levels. The histogram of the variations around the background are shown on figure 9. The noise distribution is skewed towards low values. The RMS noise associated with the data from figure 9 is 1.9 gray levels. When this value is compared to the threshold value of 45 it is concluded that the thresholding can only be marginally affected by the noise and that the possibility of noise-induced object detection is eliminated.

Spectral analysis of the background noise has been performed and figure 10 presents the power spectral density. The spectrum peaks at a wavenumber close to  $0.1 \text{ pixel}^{-1}$  and there is little noise occurring at wave numbers less than about  $1/50 \text{ pixel}^{-1}$ . This is a result of averaging over 47 pixels to obtain the background.

#### **4.2) SENSITIVITY TO LIGHT LEVEL**

A possible source of error during routine operation of the system is the one associated with the fluctuation of the light intensity in time. To obtain an estimate of the magnitude of these variations, a card with a single stain on it was scanned. For each scan, the light intensity was changed by varying the voltage input to the lamps from 12.00 to 13.00 volts. The

experiment was performed with a small and a large stain and figure 11 summarizes the results. The average sensitivity of the stain diameter to voltage changes at a nominal voltage of 12.5 volts was -13.2 and -12.4 pixels/volt for the large and small stains respectively. Therefore, to measure the stain diameter to an accuracy better than 1 pixel, it is necessary to control the voltage across the lamps to within 0.07 volts. The tolerance of 0.01 was chosen to be safe in the present application. Although the voltage to the lamps is easily controlled, this does not guarantee that the output from the lamps remains constant. As time progresses, the output from the lamps can decrease at a given voltage as a result of aging of the halogen element. To insure that lamp aging is not a problem, a light map similar to the one of figure 3 is generated before each scanning session. This map is then compared to a similar one obtained when the system calibration was last performed. Noticeable differences between the two maps indicate that either the lamp orientation, the lamp output or the focus of the camera has changed significantly. This condition calls for a recalibration of the system to define a new operating point.

#### **4.3) SPATIAL STABILITY**

Spatial stability refers to the ability of the system to perform repetitive measurements no matter where in the field of

view an object is located. To estimate the spatial stability of the system, the diameter of a single stain was measured at 9 locations on a symmetrical grid covering the whole field of view. The diameters reported in Table 1 are the average of diameters measured along two mutually perpendicular directions. The measurements were repeated 4 times in a randomized block fashion. From application of the Fisher test, the F ratio indicates that the effect of the location in the field of view on the measured diameter is not significant at the 99% confidence level (computed F ratio = 0.682 ; theoretical F ratio = 5.24). In Table 1, the overall average diameter is 21.0; hence, all estimates are within  $\pm 1$  pixel from the average.

## 5) SYSTEM CALIBRATION

The calibration of the image analysis system is performed on cards showing a single stain made by a droplet of a known diameter. The calibration cards are prepared using the NAE Droplet Generator described by Slack (1984). This droplet generator pulls one droplet at a time from a pendant drop. Immediately after its formation, the droplet is photographed in the air before it lands on a sampling card which is used for calibration. The droplet size is then measured from a print of the photograph or directly from the negative using a digitizer or a microscope. The measured droplet diameter is scaled by measurements of a needle of known diameter photographed with the

same equipment used with the NAE Drop Generator. The stain equivalent circular diameter is measured with the image analysis system.

The equivalent circular diameters of the stains are plotted against the droplet diameters and a least square fit provides the calibration equation. Both the data and the calibration curve are shown on figure 12 for a threshold level of -45. The calibration equation is given by:

$$\delta = 10.10 + 4.91 \times d_s^{0.94} \quad (3)$$

where  $\delta$  is the droplet diameter in  $\mu\text{m}$  and  $d_s$  is the stain equivalent circular diameter in pixels. The standard deviation of the residual error for this regression, which is a measure of the overall system accuracy, is equal to 3.53  $\mu\text{m}$ .

Calibration equations have been computed at threshold levels of -35 and -55 to examine the effect of the threshold on the accuracy and the sensitivity of the system. The calibration curves are presented in figure 13 and 14 and the calibration equations are:

Threshold: -35

$$\delta = 7.57 + 4.89 \times d_s^{0.94} \quad (4)$$

Threshold: -55

$$\delta = 11.97 + 4.94 \times d_s^{0.94} \quad (5)$$

The standard deviation of the residual error is equal to 3.36 for equation 4 and to 3.68 for equation 5. From these results, it can be concluded that the exact location of the threshold between the background and the stain peaks of the gray level histogram is of little importance as long as it is within 10 gray levels of the mid-point between the two peaks.

#### 6) DISCUSSION AND CONCLUSION

The image analysis system presented here is a valuable tool in the analysis of spray samples. It has been shown that the digitized image can be corrected for background and that background noise can be ignored without affecting the accuracy of the measurements. A tight control of the illumination of the target results in good repeatability of the measurements from sample to sample. Also, measurements have been shown to be independent of the location of the stain in the camera field of view.

The calibration of the system has been performed for three different threshold levels. This has demonstrated that the

choice of the threshold level is not a critical operational parameter since the accuracy of the system is marginally affected by this choice over the range of threshold levels considered. One can infer from equation 3 that the detection limit of the system corresponds to a stain made by a  $15.0\text{ }\mu\text{m}$  droplet. However since stains of less than 10 pixels in area should be rejected to minimize the impact of dirt particles, the practical detection limit corresponds to a  $26.3\text{ }\mu\text{m}$  drop.

From a user's point of view, the system is easy to operate requiring very little operator intervention. All the operator has to do to initiate a scanning session is to generate a light map that should be compared to the one generated when the system was last calibrated. When the comparison shows no noticeable differences, then the scanning session can be started.

The system takes between 75 and 90 seconds to analyze a sample depending on stain density. The sample area is  $19.1\text{ cm}^2$  ( $2.96\text{ in}^2$ ). This compares favorably with the system described in Last et al. (1987) where a  $1.6\text{ cm}^2$  ( $0.25\text{ in}^2$ ) sample is analyzed in 60 to 80 seconds at 30 microns per pixel, which is two thirds of the resolution of the system being reported here.

All the software required to operate the system has been integrated into a menu-driven environment called Agriscan. This facilitates its operation and reduces considerably the time required to train a new operator. Various diagnostic routines

are available to verify system operation and to examine portions of the image in greater detail.

So far, the system has been used to analyze spray samples. However both the software and hardware can be used to analyze any type of image provided that the contrast between the background and the features of interest is sufficiently high. Other applications of the system are planned in the area of weed cover estimation from infrared slides and of weed seed counting. Both these applications will require the development of some pattern recognition algorithms which are also required for the analysis of overlapping stains on spray samples.

#### 7) ACKNOWLEDGMENTS

Most of the work described in this paper was performed at the Flight Research Laboratory of the National Research Council. We would like to thank Mr. A.Barszczewski and Mr. R.W. Lee for their significant contributions. Agriculture Canada and the National Research Council of Canada shared the capital expenditures.

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Table 1: Effect of the location in the field of view on measured diameters.

| Analysis of variance |                    |      |      |                |      |             |      |      |      |
|----------------------|--------------------|------|------|----------------|------|-------------|------|------|------|
| Diameters [pixels]   |                    |      |      |                |      |             |      |      |      |
| Location             | 1                  | 2    | 3    | 4              | 5    | 6           | 7    | 8    | 9    |
| Block 1              | 21                 | 21.5 | 20.5 | 21.5           | 21   | 21.5        | 20.5 | 20.5 | 20.5 |
| Block 2              | 20.5               | 21   | 21.5 | 20.5           | 21   | 20.5        | 21.5 | 21   | 20.5 |
| Block 3              | 21.5               | 21.5 | 21   | 21             | 21   | 21          | 20.5 | 21   | 22   |
| Block 4              | 21                 | 21   | 21   | 21             | 20.5 | 21          | 20.5 | 20   | 21.5 |
| source of variation  | Degrees of Freedom |      |      | Sum of Squares |      | Mean Square |      |      |      |
| between classes      | 8                  |      |      | 1.125          |      | 0.140       |      |      |      |
| within classes       | 27                 |      |      | 5.562          |      | 0.206       |      |      |      |
| total                | 35                 |      |      | 6.687          |      | 0.191       |      |      |      |
|                      |                    |      |      | F Ratio        |      | 0.682       |      |      |      |
|                      |                    |      |      | F:27:8         |      | 5.24        |      |      |      |



Gray level

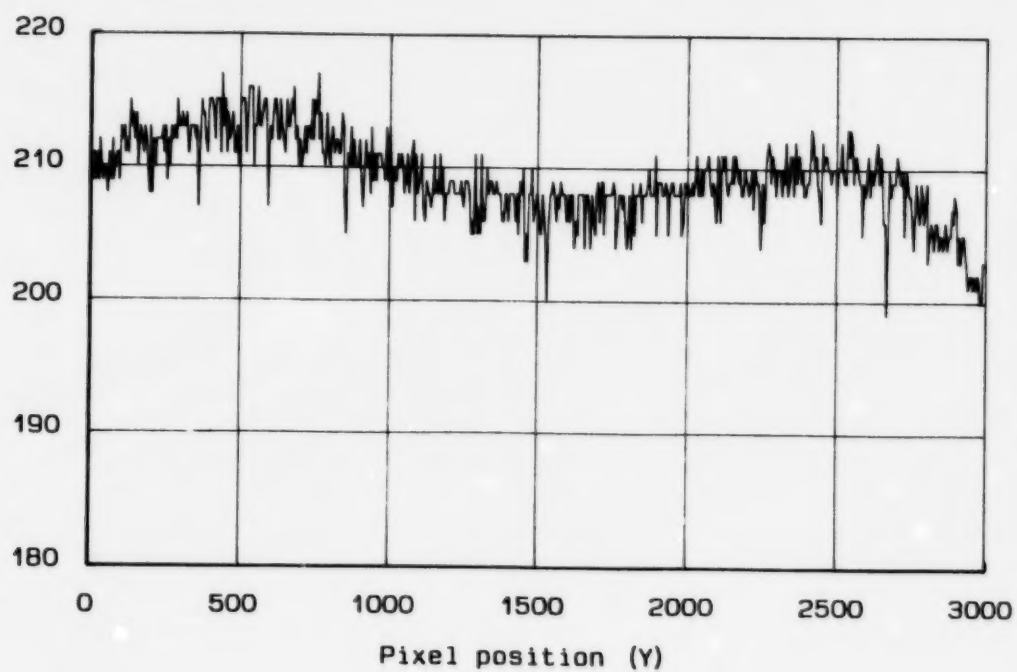


**FIG. 1: RAW GRAY LEVEL DATA ALONG A SINGLE SCAN LINE**

Gray level  
offset: 200

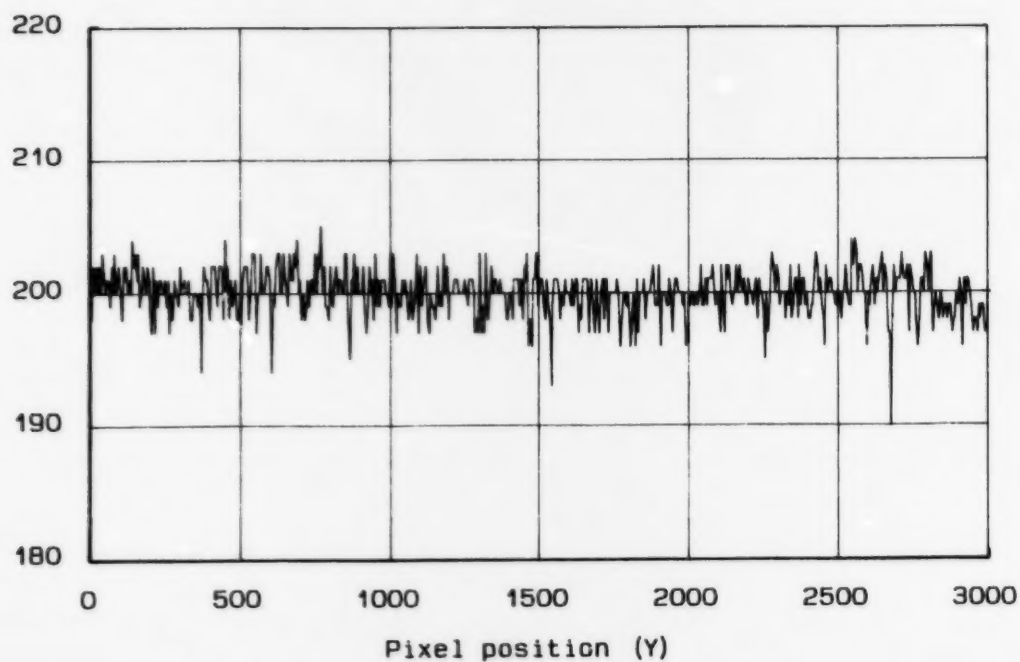


**FIG. 2: GRAY LEVEL DATA ALONG A SINGLE LINE, CORRECTED FOR BACKGROUND**

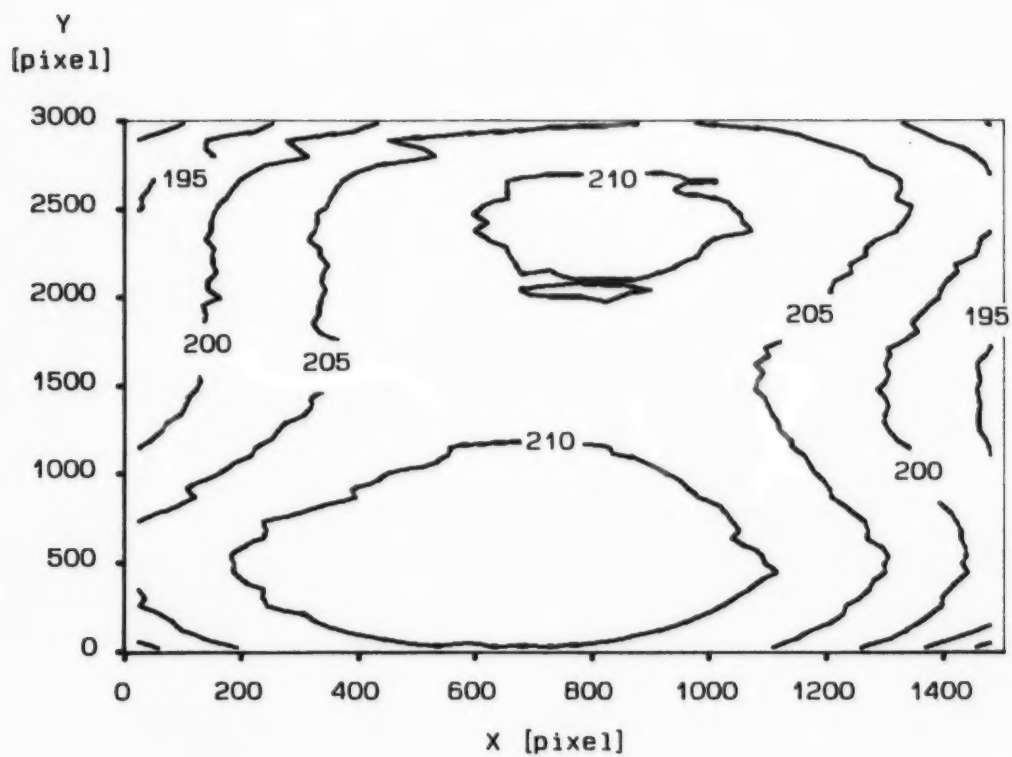


**FIG. 3: CONTOUR PLOT OF THE BACKGROUND**

Average gray level  
relative to background

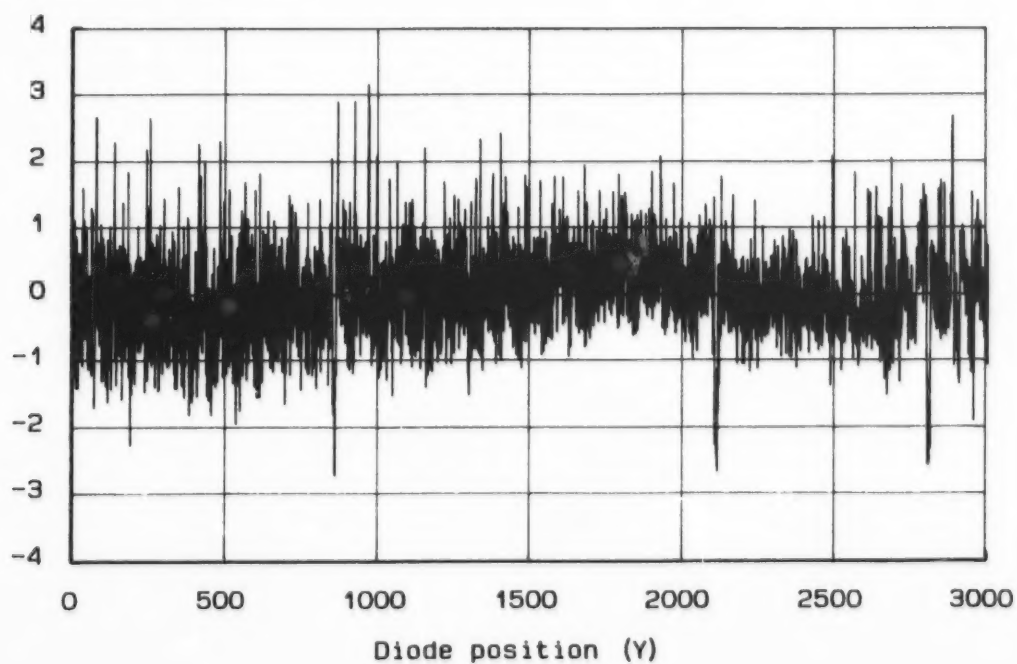


**FIG. 4: MEAN DIODE READING CORRECTED FOR BACKGROUND OVER THE WHOLE FIELD OF VIEW**

Relative  
Frequency

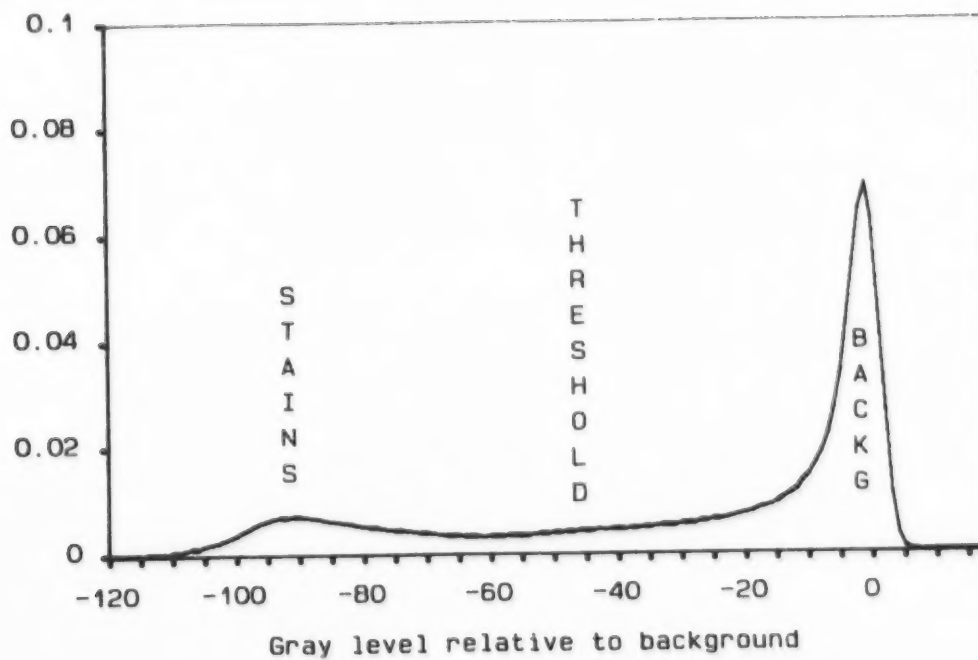


FIG. 5: GRAY LEVEL HISTOGRAM OF A HEAVILY STAINED CARD

Gray level

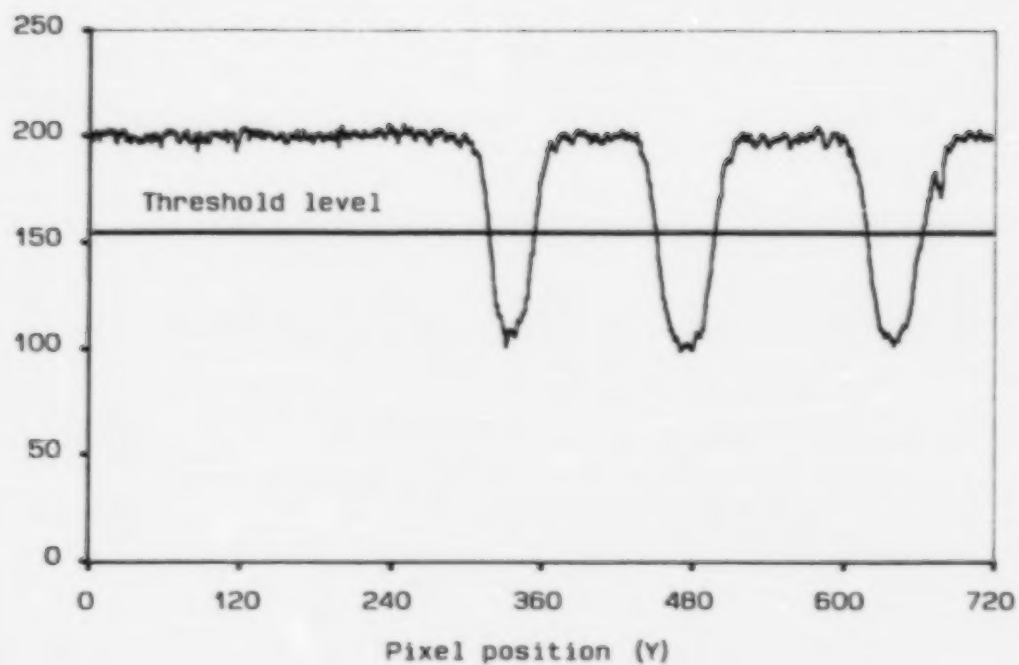


FIG. 6: SIGNAL AMPLITUDE VERSUS SIGNAL AND BACKGROUND NOISE

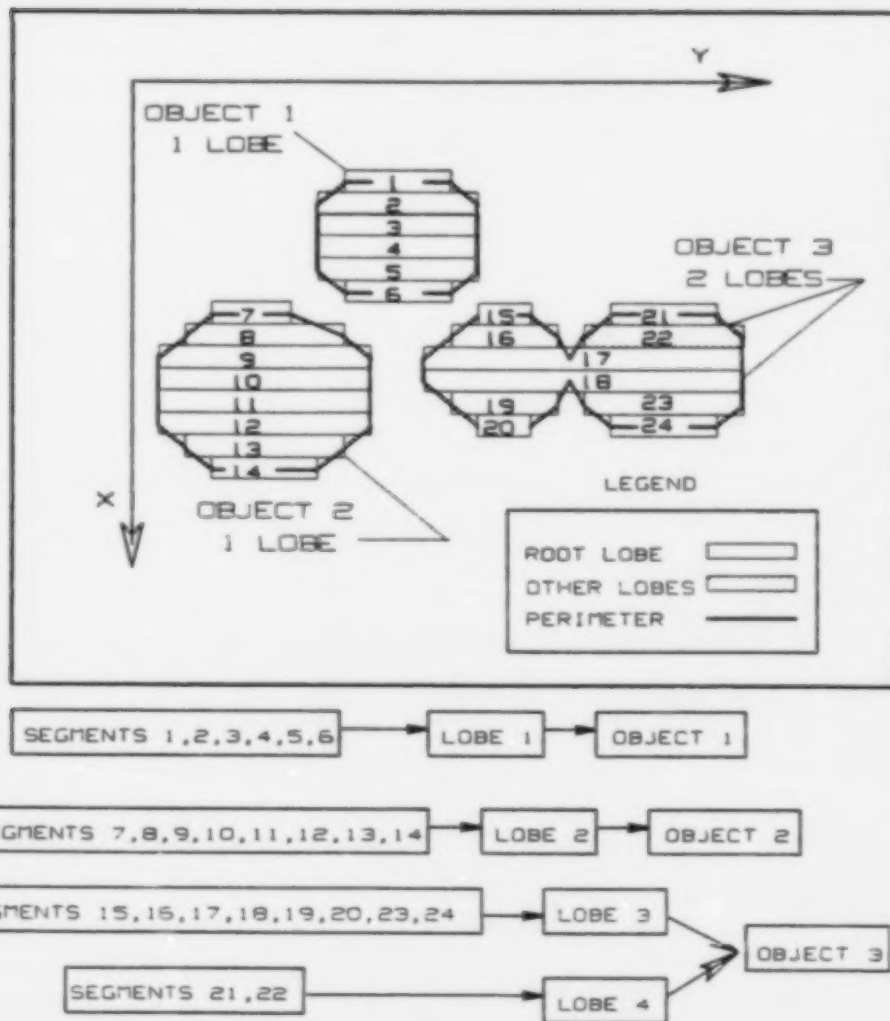


FIG. 7: ILLUSTRATION OF THE OBJECT SEGMENTING APPROACH

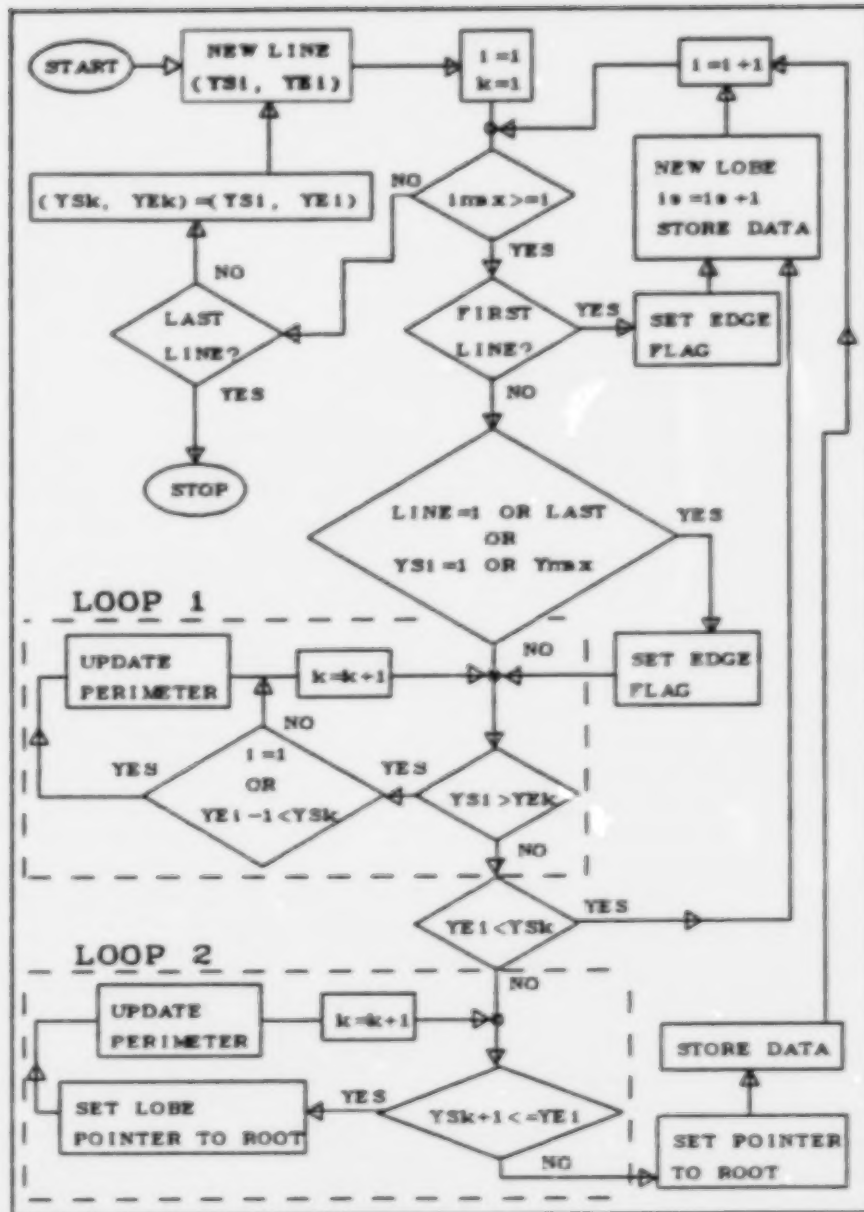


FIG. 8: SEGMENTING LOGIC FLOWCHART

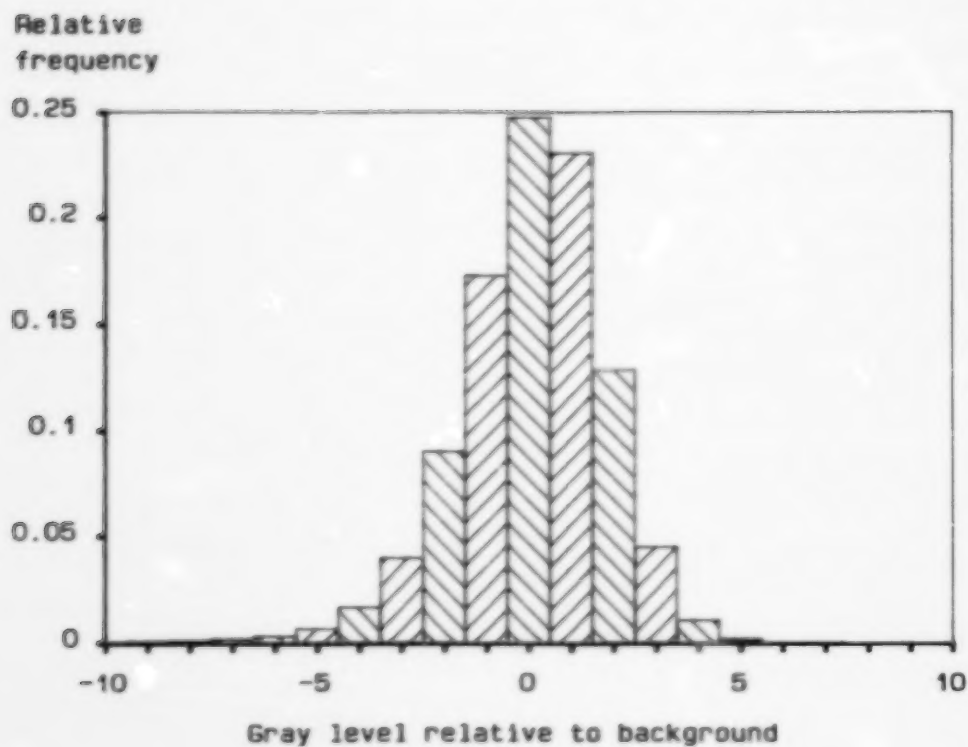


**FIG. 9: HISTOGRAM OF THE BACKGROUND NOISE**

Non-dimensional  
Power spectral density

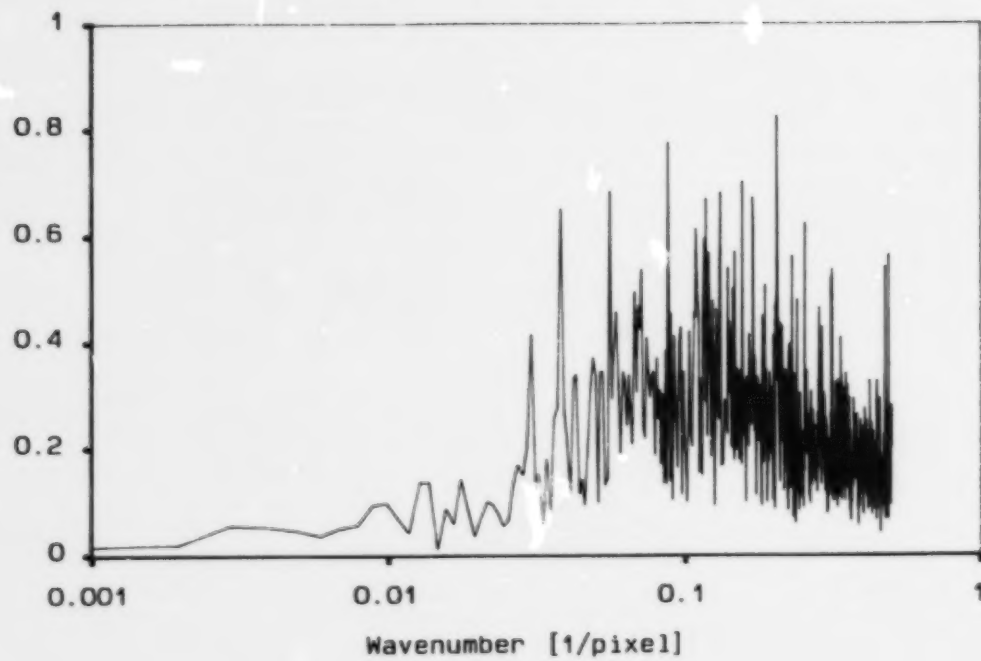


**FIG. 10: POWER SPECTRAL DENSITY OF THE BACKGROUND NOISE**

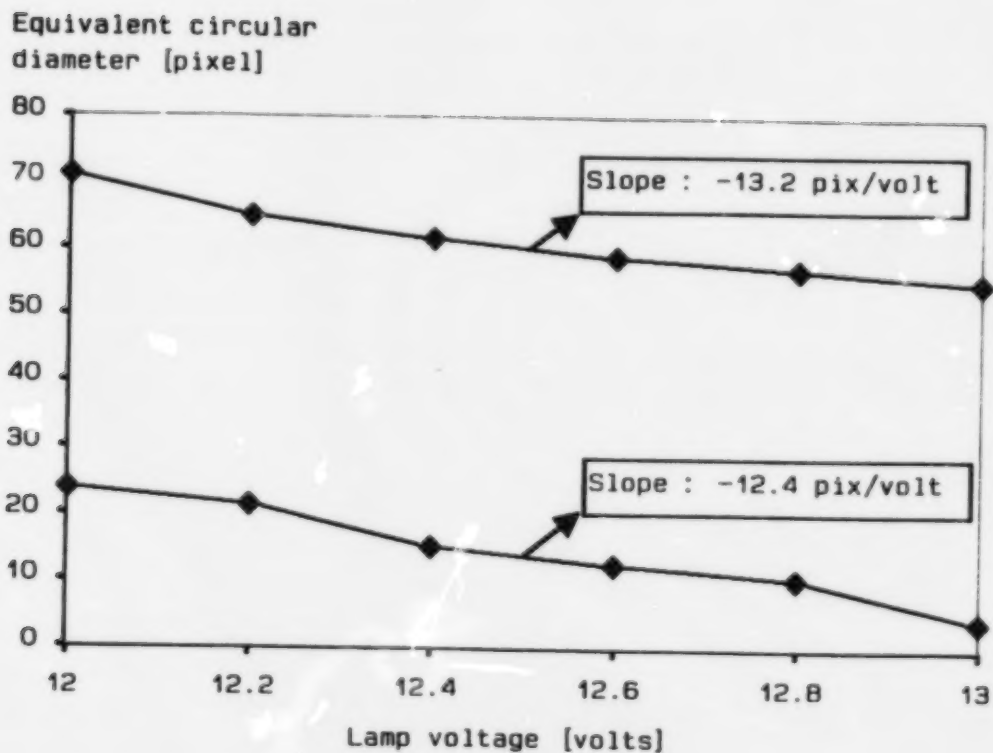


FIG. 11: EFFECT OF THE VARIATION IN THE LAMP VOLTAGE ON THE MEASUREMENT OF THE EQUIVALENT CIRCULAR DIAMETER

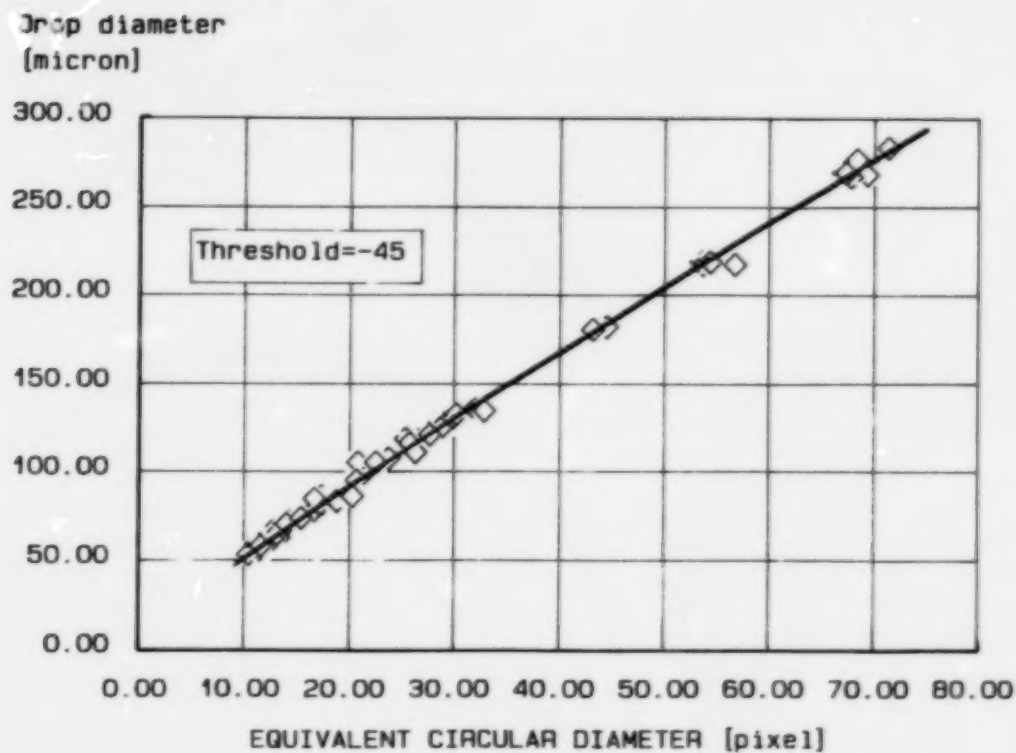


FIG. 12: CALIBRATION CURVE AT A THRESHOLD LEVEL OF -45

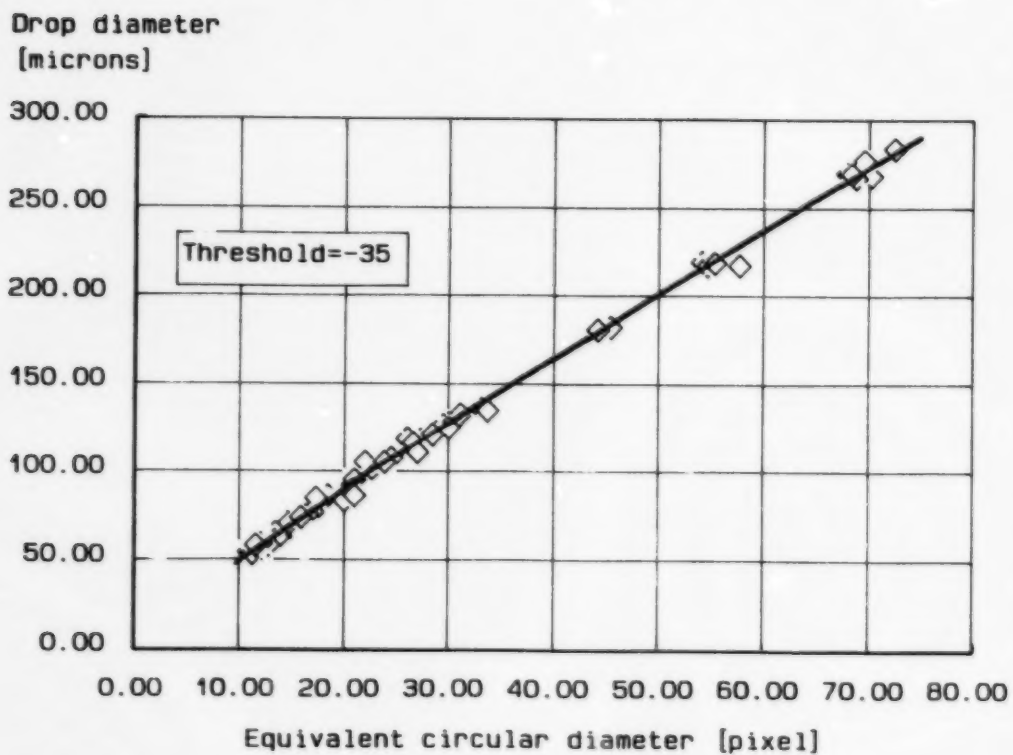


FIG. 13: CALIBRATION CURVE AT A THRESHOLD LEVEL OF -35

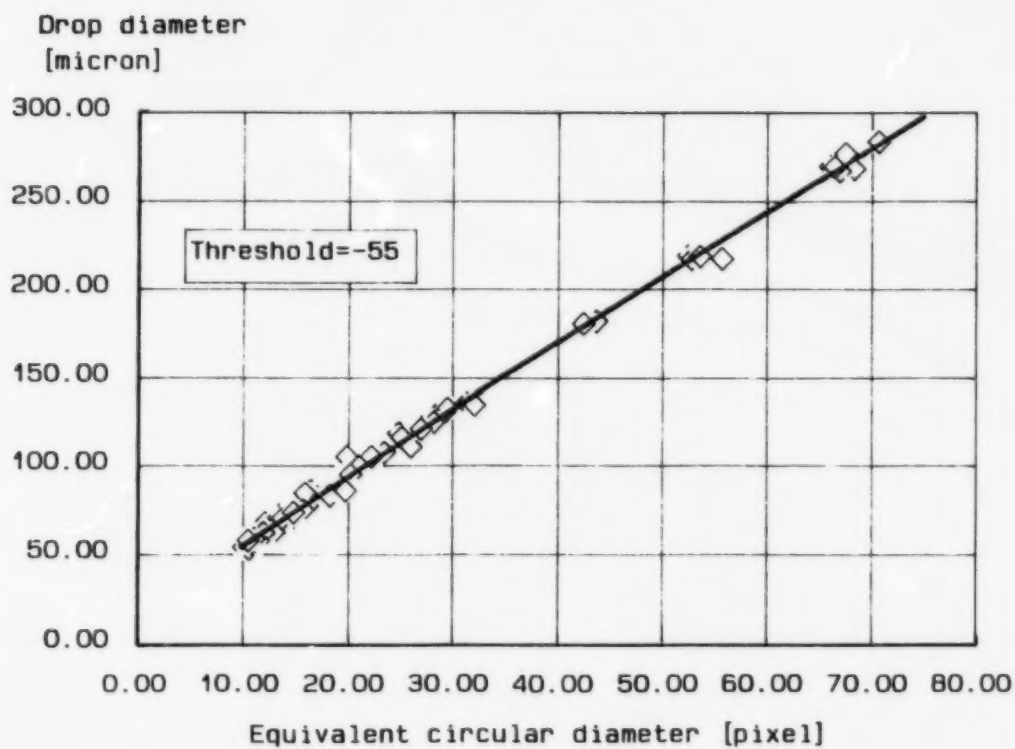


FIG. 14: CALIBRATION CURVE AT A THRESHOLD LEVEL OF -55

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| SUMMARY/SOMMAIRE                                                                                                                                                                                                                                                                                                                                                                                                                                |              |                                |       |                  |
| <p>A system for analyzing spray samples based on an electronic digitizing camera is described. The implementation and development of both the hardware and the software are discussed as well as the system performance. The system is capable of digitizing a sample into 1504 by 3008 pixels using 256 gray levels. The resolution is 10 µm at the image plane and droplet diameters can be estimated with a most likely error of 3.5 µm.</p> |              |                                |       |                  |
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